Title: Boundary-layer flow simulations over ablating woven thermal protection system material.

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Spallation is the mechanical removal of small chunks of material gets removed typically due to high shear conditions of the flow field. This reduces the ability of the thermal protection system (TPS) material to protect the spacecraft as well as cause turbulence in the flow causing higher heating rates. In this work, we focus on the material removal through ablation and high shear flow within the boundary layer region of woven TPS material. Woven TPS (WTPS) material is the latest class of material developed by NASA, to be used within the next generation of space flights. They are complex interlocked weaves designed to create a rigid structure that is highly resistant to heat and can be easily designed and tailored for a wide variety of entry environments. Due to material removal resulting from chemical degradation, the structural integrity of TPS material is affected. Spallation occurs when this structurally compromised material is exposed to the high shear flow conditions within the boundary layer.

In order to understand the spallation mechanism within WTPS material, we first perform the material removal simulations which occur primarily through oxidation to obtain the microstructure at various stages of degradation. These simulations are performed using the Porous Microstructure Analysis (PuMA) software developed at NASA Ames [1]. The micro-structure geometry used within these simulations were generated artificially to be similar to the 3D weave architecture of MSR-EEV (Mars Sample Return - Earth Entry Vehicle) [2].

The various eroded TPS micro-structures are then subjected to the boundary layer flow conditions to obtain critical surface quantities which contribute to the structural failure mechanism such as heat flux, pressure, and shear stress. The direct simulation Monte Carlo (DSMC) methodology [3] is used to perform these simulations in order to accurately capture the strong gradients within the high-temperature boundary layer flow over the intricate geometry of WTPS material [4]. The boundary layer profile is directly taken from the Computational Fluid Dynamics (CFD) simulation and provided as boundary conditions to the DSMC inlet and outlet. Further, the variation of these properties as the microstructure undergoes changes due to oxidation is also investigated. Finally, these quantities are used as input in PuMA to understand the material expansion/compression and strain within the woven TPS geometry and help in developing a comprehensive spallation and structure failure model.

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